

Introduction: The NASA Mars Exploration Program has four main goals: (i) determine if life ever arose there, (ii) understand the processes and history of its climate, (iii) determine the evolution of its surface and interior, and (iv) prepare for human exploration of Mars [1]. These goals are embodied in the NASA Mars exploration strategy “Follow the Water.” Current Mars exploration tactics for lander missions build on knowledge gained by prior orbital investigations; the science rationale for choosing landing sites is based on the current best interpretation of the geology. A future Mars sample return mission will greatly exceed in cost typical lander missions because of the need to design for return to Earth and the infrastructure needed on Earth to curate and process the samples safely and cleanly. Because of this added cost burden, expectations for science return are higher. There must be some prospect that the returned samples will allow for testing higher level hypotheses relevant to NASA’s goals. Site selection must be based on knowledge gained from prior *in situ* measurements to enhance the prospects for successfully meeting these goals. I will argue that Meridiani Planum should be that site.

Geology of Meridiani Planum: Meridiani Planum is a low-relief terrain with few craters in the central portion of Sinus Meridiani [2]. Orbital thermal emission spectrometry showed that the plains have a significant cover of hematite, posited to have formed from aqueous solutions [3, 4]. The rocks of Meridiani Planum form a nearly horizontally layered sequence perhaps 800 meters thick, of which the hematite-rich units are only a portion [2, 5]. Although prior to *in situ* investigation the rocks were thought to be volcanoclastic [5], the Mars Exploration Rover Opportunity has shown that the outcrops in its immediate vicinity are sedimentary [6]. This is inferred to hold for the entire section in Meridiani Planum [2]. The rocks investigated by Opportunity represent only about 1% of the section and are near its top [2]; they are among the youngest sediments in the section, and are interpreted to be Late Noachian or Early Hesperian in age [2, 5].

Opportunity and Meridiani Sediments: The ~7 meter sedimentary section investigated by Opportunity is interpreted to be a sequence of wind and water transported clastic materials [6-8]; the synopsis here (Figure 1) is from [7]. The lower unit consists of cross-bedded sandstones interpreted to be fossil eolian dunes. Above this lies an eolian sand sheet composed of fine-scale planar-laminated to low-angle-stratified sandstones. The boundary between the lower and middle

units is an eolian deflation surface indicating a period of erosion. The top of the middle unit is defined by a zone of diagenetic recrystallization. The upper unit consists in part of eolian sand sheet sediments and in part of interdune playa lake sediments showing sedimentary structures indicative of water transport.

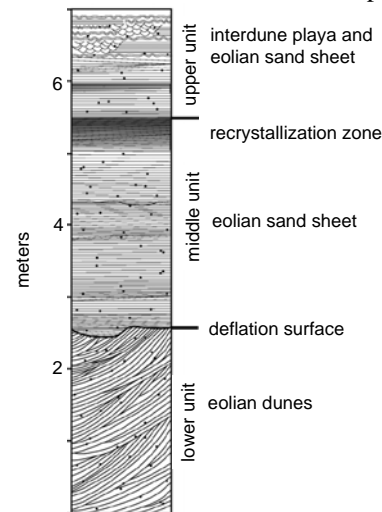


Figure 1. Interpretive sedimentary section investigated by Opportunity, after [7]. The black dots represent the ubiquitous diagenetic hematitic concretions.

The mineralogy of the sediments has been constrained by Mössbauer spectrometry and miniature thermal emission spectrometry (Mini-TES). The iron mineralogy is dominated by hematite, jarosite, an unidentified ferric phase (Fe₃D₃) and pyroxene, with a very small amount of olivine [9]. Mini-TES spectra for light-toned outcrops also demonstrate the presence of jarosite and hematite, and identify Mg- and Ca-bearing sulfates, Al-rich opaline silica, plagioclase feldspar, and possibly nontronite [10]. (Mini-TES spectra are on natural rock surfaces, while Mössbauer spectra are from rock interiors exposed by grinding – the two data sets are not on equivalent materials.)

The sediments in Meridiani Planum are interpreted to have been derived from muds from an evaporating playa lake [11]. The muds were composed of primary igneous minerals, siliciclastic alteration materials and evaporite minerals. Desiccation of the playa lake exposed the surface to wind erosion allowing sand-sized dried mud particles to be transported by wind to the site of deposition. These grains form the framework of the Meridiani rocks that were subsequently affected by diagenesis.

Meeting NASA Science Goals with Meridiani Sediments: The fourth goal listed above is more connected to engineering requirements for human missions than to Mars science. It can be addressed probably equally well by samples from just about any site on Mars, and will not be discussed here.

Determine if life ever arose on Mars. Orbital [3, 4] and *in situ* [6-12] investigation of Meridiani Planum provide a compelling case for aqueous processes having occurred at this site, including the likelihood that standing pools of water once existed on the surface [7, 8]. Thus, rocks returned from Meridiani Planum hold a strong potential for harboring signs of past life, if it ever existed. Examination of samples by electron microbeam techniques to search for microfossils and biogenic mineralization, and by geochemical analysis to search for organic chemical and isotopic fractionations diagnostic of biological activity can test for past (or extant) life. These analyses might best be done on cores intercepting playa lake sediments below the current erosion surface as this would minimize the chance that Mars' current environment has degraded the evidence.

Understand the processes and history of climate on Mars. Clear signs of aqueous activity by ground water and standing water at Meridiani Planum require that the climate was different at the time of deposition and diagenesis. Although some constraints can be placed on the nature of the diagenetic solutions from the mineralogy and chemistry determined *in situ* [11, 12], these data lack the precision and completeness that can be achieved by laboratory study. Examination of returned rocks will allow for complete characterization of mineralogy, mineral compositions and compositional zoning, textural context, and bulk chemical and stable isotopic composition that will allow for much more detailed and precise modeling of fluid evolution. This would certainly be true for the post-depositional diagenesis process. If later diagenesis did not completely overprint the evidence, it may be possible to elucidate the chemistry of the standing waters in which the sediments of the upper unit were deposited. These waters were in contact with the atmosphere, and the compositions of minerals derived from them may thus yield more direct information on the ancient Mars atmosphere and climate. Returned samples will thus allow for greater fidelity of models with nature. A major advance, however, would be to determine absolute ages for this climatic period. This can be accomplished by radiometric age dating of key minerals. Jarosite, formed by aqueous alteration, is amenable to K-Ar (and possibly Ar-Ar) dating to yield its formation age [13], and dating by other radiometric techniques may also be feasible [14].

Determine the evolution of the surface and interior of Mars. In addition to addressing climatic issues, Meridiani sediments would yield important new insights into the evolution of the surface and interior of Mars. Pyroxene and plagioclase are significant components of the outcrops, and they and olivine are components of the younger eolian bedforms [9, 10, 15]. These phases likely are remnants of primary crustal igneous rocks. Their preservation demonstrates that chemical weathering was not 100% effective, opening the door for investigations of the evolution of the surface and interior. One outcome would be determination of the chronology of the development of the crust. Some accessory phases concentrate the parent nuclides of radiometric chronometers. Zircon and baddeleyite concentrate U and individual grains can be dated using microbeam techniques [16, 17]. By using laser extraction techniques, Ar-Ar dating of individual major mineral grains can be done [18]. These techniques would yield information on the chronology of formation of the crust that was altered and eroded to provide the Meridiani sediments. The assemblage and mineral compositions of remnant igneous grains can be used to infer the nature of the crust supplying the detritus [19]. Terrestrial experience [16, 20] shows that by using the full panoply of modern microbeam analytical instrumentation, details of the formation of Mars' ancient crust may be discovered, even if that crust no longer exists.

References: [1] Johnson J. R. et al. (2008) *Mars Science Goals, Objectives, Investigations, and Priorities*, <http://mepag.jpl.nasa.gov/reports/index.html>. [2] Edgett K. S. (2005) *Mars I*, 5. [3] Christensen P. R. et al. (2000) *JGR-Planets* 105, 9623. [4] Christensen P. R. et al. (2001) *JGR-Planets* 106, 23873. [5] Hynek B. M. et al. (2002) *JGR-Planets* 107, 5088. [6] Squyres S. W. et al. (2004) *Science* 306, 1709. [7] Grotzinger J. P. et al. (2005) *EPSL* 240, 11. [8] Squyres S. W. et al. (2006) *Science* 313, 1403. [9] Morris R. V. et al. (2006) *JGR-Planets* 111, E12S15. [10] Glotch T. D. et al. (2006) *JGR-Planets* 111, E12S03. [11] McLennan S. M. et al. (2005) *EPSL* 240, 73. [12] Clark B. C. et al. (2005) *EPSL* 240, 95. [13] Keith W. J. et al. (1979) *USGS Prof. Pap.* 1124-C, C1. [14] Papike J. J. et al. (2006) *GCA* 70, 1309. [15] Glotch T. D. & Bandfield J. L. (2006) *JGR-Planets* 111, E12S06. [16] Pidgeon R. T. & Nemchin A. A. (2006) *Precam. Res.* 150, 201. [17] Herd C. D. K. et al. (2007) *LPS XXXVIII*, #1664. [18] Walton E. L. et al. (2007) *M&PS* 42, A159. [19] Piper D. J. W. et al. (2007) *Can. J. Earth Sci.* 44, 665. [20] Valley J. W. et al. (2005) *Contrib. Min. Pet.* 150, 561.